PREPARED BY:
N. BERCUSON, D. MATHERS, N. BOURDON, L. KOZALK
INDUSTRIAL TECHNOLOGY / MANITOBA RESEARCH COUNCIL
WINNIPEG, MANITOBA

GASOHOL FLEET TEST

MANITOBA TELEPHONE SYSTEM

MG-11880

2 (80-18)
MARCH 1983

MANITOBA/CANADA CONSERVATION AND RENEWABLE ENERGY DEMONSTRATION AGREEMENT

The availability of secure and affordable energy supplies is a subject of national concern. It is an accepted fact that our primary energy sources - oil and natural gas - are becoming less accessible and more costly. However, Canada is well-endowed with non-renewable and alternative resources that can provide a bridge into the future.

To this end, the governments of Manitoba and Canada have entered into a Conservation and Renewable Energy Demonstration Agreement which was signed May 9, 1980 and terminates March 31, 1984. The Agreement is dedicated to the development and demonstration of conservation and renewable energy technologies. Equally cost-shared by the provincial and federal governments, the program has a total budget of $18-million.

The objectives of CREDA are:

- To develop and demonstrate promising new technologies, which, when widely adopted, will exploit renewable resources, conserve energy and/or use energy more efficiently.
- To develop broad public awareness of the potential of renewable energy and conservation technology.
- To provide opportunities for the commercial application of the technologies within Manitoba.
- To create economic spin-off benefits for manufacturing, industry and commerce.
- To create employment in new or existing energy-related industries.

Opinions contained in this report are those of the author(s) and are not necessarily those of the Manitoba Department of Energy and Mines, or Energy, Mines and Resources Canada.

Use of company names, brand names or trademarks is made for informational purposes only and does not constitute endorsement or recommendation over similar products or services.

TABLE OF CONTENTS

		Page
1.0	Executive Summary	1
2.0	Introduction	3
3.0	Scope and Objectives	9
3.1	Objectives	9
3.2	Scope of Work	9
4.0	Methods and Test Procedure	11
4.1	Fleet Vehicle Selection and Operation	11
4.2	Driveability Assessment	11
4.3	Fuel Analyses	15
4.4	Engine Dynamometer Tests	15
4.4.1	Test Procedures	15
4.5	Chassis Dynamometer Tests	16
4.5.1	Test Procedure	16
4.6	Fuel System Compatibility	17
4.6.1	Test Procedures	17
4.7	Engine Durability	17
4.8	Data Analysis	17
4.8.1	Mainstem Data Collection System	17
4.8.2	Paired Significance Tests	17

Page

5.0 Results and Discussion 19

5.1 Driveability 19

5.2 Fuel Analyses 19

5.3 Engine Dynamometer Tests 25

5.4 Fleet Performance Comparisons 28

5.4.1 Specific Fuel Consumption Comparisons - Paired Historic Fleet Data 28

5.4.2 Specific Fuel Consumption - Gasohol and Gasoline Control Fleet 28

5.5 Chassis Dynamometer Tests 31

5.6 Fuel System Compatibility 36

5.7 Engine Durability 36

5.8 Economic Considerations 36

6.0 Summary and Conclusions 39

7.0 Recommendations 41

Appendix 1 Test Procedure Used for Determining the Ethanol Content of Gasohol 43

Appendix 2 Tabulated Results of Engine Dynamometer Tests on a 2.3L Ford Engine Using Gasohol and Gasoline 47

Appendix 3 Statistical Analysis of Fuel and Energy Consumption Data ... 59

Appendix 4 Results of Fuel System Compatibility Tests with Gasohol 63

Appendix 5 Photographs of Engine Cylinder and Valve Assemblies after Fleet Test Completion 71

List of Tables

		Page
Table 1	Matched Fleet Vehicles	12
Table 2	Unmatched Fleet Vehicles	13
Table 3	Mean Monthly Summer and Winter Temperatures in Winnipeg	25
Table 4	Mean Fuel Consumption of the Gasohol Fleet Vehicles Compared with Mean Fuel Consumption of the Same Vehicles When Operated on Gasoline Prior to Conversion	29
Table 5	Mean Energy Consumption of the Gasohol Fleet Vehicles Compared with Mean Energy Consumption of the same Vehicles Operated on Gasoline Prior to Conversion	30
Table 6	Mean Specific Fuel Consumption Comparison of the 18 Matched Vehicles in the Gasohol and Control Fleets	32
Table 7	Mean Specific Energy Consumption Comparison of the 18 Matched Vehicles in the Gasohol and Control Fleets	33
Table 8	List of Vehicles used in Chassis Dynamometer Comparison Tests	34
Table 9	Chassis Dynamometer Results for 48 km/h Simulated Urban Driving	35
Table 10	Chassis Dynamometer Results for 88 km/h Simulated Highway Driving	37
Table 11	Ratios of Brake Specific Fuel Consumption (Gasohol/ Gasoline)	49
Table 12	Comparison of Maximum Torque and Maximum Power Output	50

List of Figures

		Page
Figure 1	Daily Log Sheet for Completion by Fleet Drivers	14
Figure 2	Summary of Driveability Results from Gasohol Fleet Daily Driver Log Sheets	20
Figure 3	Variations in Ethanol Content of the Gasohol Test Fuel over the Test Period	21
Figure 4	Variations in Water Content of the Gasohol Test Fuel over the Test Period	22
Figure 5	Variations in Reid Vapour Pressure of the Gasohol Test Fuel During the Test Period	23
Figure 6	Comparative Fuel Distillation Curves for Summer Blends of Esso 2000 Unleaded Gasoline and Mohawk Gasohol	24
Figure 7	Brake Specific Fuel Consumption Comparisons for a 2.3L Ford Engine Operating at 3500 rpm	27
Figure 8	Comparison of Overall Engine Characteristics	51
Figure 9	Brake Specific Fuel Consumption at 1000 rpm	52
Figure 10	Brake Specific Fuel Consumption at 1500 rpm	53
Figure 11	Brake Specific Fuel Consumption at 2000 rpm	54
Figure 12	Brake Specific Fuel Consumption at 2500 rpm	55
Figure 13	Brake Specific Fuel Consumption at 3000 rpm	56
Figure 14	Brake Specific Fuel Consumption at 4000 rpm	57
Figure 15	Brake Specific Fuel Consumption at 4500 rpm	58
Figure 16	Fuel Distillation Curves for the Gasoline Used for Immersion Tests	69
Figure 17	Fuel Distillation Curves for the Gasohol Used for Immersion Tests	70

List of Figures (cont'd)

		Page
Figure 18	Type 9 Engine Cylinder Assembly (Operated on Gasohol)	73
Figure 19	Type 9 Engine Cylinder Assembly (Operated on Gasoline)	73
Figure 20	Type 9 Engine Valve Assembly (Operated on Gasohol)	75
Figure 21	Type 9 Engine Valve Assembly (Operated on Gasoline)	75
Figure 22	Type 3 Engine Cylinder Assembly (Operated on Gasohol)	77
Figure 23	Type 3 Engine Cylinder Assembly (Operated on Gasoline)	77
Figure 24	Type 3 Engine Valve Assembly (Operated on Gasohol)	79
Figure 25	Type 3 Engine Valve Assembly (Operated on Gasoline)	79

1.0 EXECUTIVE SUMMARY

1.1 This fleet test was funded under the Manitoba/Canada Conservation and Renewable Energy Demonstration Agreement (CREDA). Signed in 1980, the Agreement has a total budget of $18 million, shared equally between the province of Manitoba and the federal government. It is envisioned that the CREDA program will lead to the development of new technologies which will foster energy conservation and exploit renewable resources. Stimulation of public awareness, commercial applications, economic spin-off benefits for Manitoba industry and employment creation are important program objectives.

The objective of the test was to assess the feasibility of gasohol as an automotive fuel in Manitoba, by comparing the overall performance and operating costs of a test fleet operating on gasohol with those of a control fleet operating on unleaded gasoline. CREDA's contribution to the study was $129,000. The Manitoba Telephone System contributed $60,250.

1.2 The gasohol used in the test fleet was produced by the Mohawk Oil Co. Ltd. and is a blend of 10% ethyl alcohol and 90% Esso 2000 unleaded gasoline. The control fleet was fueled with Esso 2000 unleaded gasoline.

1.3 The test and control fleets each consisted of 25 vehicles taken from the existing Manitoba Telephone System fleet of service vehicles. Each fleet was composed of a selection of similar vehicles, ranging from subcompact automobiles with a mass of 760 kg to panel trucks with a mass of 5460 kg. Engine displacements varied from 1.57 to 5.74L

1.4 During the 22 month test period the gasohol test fleet travelled a cumulative distance of about 750,000 km, while the gasoline control fleet travelled about 1,000,000 km.

1.5 Periodic fuel analyses, made throughout the test, indicated that the ethanol content of the gasohol ranged from 10.2 to 11.2% by volume. Moisture content of the gasohol ranged from 0.01 to 0.14% while Reid vapour pressure varied from 97 to 103 kPa.

1.6 The performance of gasoline and gasohol was compared by using three specific types of tests: 1. General driveability and relative fleet fuel consumption were determined by driver surveys and gross fuel use data from normal urban and rural vehicle operation. 2. Specific fuel consumption

was determined by controlled chassis dynamometer tests on a series of selected vehicles utilizing representative driving cycles. 3. Detailed engine operating characteristics, on both fuels, were determined for one engine, utilizing an engine dynamometer and a standard engine performance test procedure.

1.7 Specific test results are as follows:

(a) Driveability: No differences in driveability and overall vehicle performance were apparent between vehicles operating on gasohol and gasoline. Fleet drivers operating gasohol fueled vehicles were satisfied with vehicle operation and reported similar performance with either gasoline or gasohol. In most cases, the same drivers operated the same vehicles before and after conversion to gasohol. No weather related problems were encountered with the gasohol powered vehicles during the demonstration.

(b) Relative Fleet Fuel Consumption: Because of limited gasohol availability during the test, the gasoline control fleet was operated primarily in rural areas, while the gasohol test fleet was operated primarily in two urban areas. As a result, comparison of overall fleet fuel consumption data for the two fleets was not valid. To permit a comparison of overall fleet fuel consumption, the specific fuel consumption of each of the 25 gasohol vehicles was compared to the specific fuel consumption of each of these vehicles, when operating on gasoline, for the 12 month period before initiation of the fleet test. In both cases, operation was in urban areas. Results of this comparison indicated no significant difference in specific fuel consumption for the two fleets. Further analysis indicated that the specific energy consumption of similar vehicles was lower when operated on gasohol than when operated on gasoline. Significant at the 90% confidence level, this difference in specific energy consumption varied from 2 to 107 MJ/100 km.

(c) Chassis Dynamometer Tests: Chassis dynamometer tests, comparing nine different vehicles operating alternatively on gasoline and gasohol, were conducted at load conditions simulating urban driving at 48 km/h and highway driving at 88 km/h. These tests eliminated the many uncontrolled variables that occur in fleet comparisons, permitting a valid comparison of specific fuel consumption of similar vehicles operating on gasohol and gasoline in urban and highway driving conditions.

Test results indicated that the specific fuel consumption was significantly less (90% confidence level) for vehicles operated on gasohol in urban driving conditions than for the same vehicles operated on gasoline. In simulated urban driving, gasohol consumption was 1.7% less than gasoline consumption, resulting in a saving of about 22¢/100 km on the basis of an equivalent of 44¢/L for each fuel. In simulated highway driving, specific fuel consumption was also significantly less (85% confidence level) for vehicles operated on gasohol than for the same vehicles operated on gasoline. In this comparison, gasohol consumption was 1.5% less than gasoline consumption.

(d) Engine Dynamometer Tests: In comparative engine dynamometer tests on a conventional 2.3 L automotive engine, the maximum power output with gasohol was about 7% greater than with gasoline. At maximum load, the brake specific fuel consumption was as much as 10% lower with gasohol than with gasoline.

(e) Engine Durability: There was no difference in routine engine maintenance requirements for vehicles operated on gasoline or gasohol. There was no evidence that ethanol in the gasohol caused any deterioration of fuel system components. Disassembly and inspection, at test completion, of two types of engines operated on gasohol and two similar engines operated on gasoline, indicated no differences in engine wear on either set of engines.

1.8 Overall test results indicated that gasohol is a viable fuel alternative to gasoline. If gasohol is available at the same unit cost as gasoline, a fleet operator could probably realize from 1 to 2% savings in fleet operating costs by using gasohol instead of gasoline.

1.0 SOMMAIRE

1.1 Cet essai a été financé dans le cadre de l'Entente Canada-Manitoba de démonstration des économies d'énergie et des énergies renouvelables (CREDA) conclue en 1980 entre le gouvernement du Manitoba et le gouvernement fédéral. Ce programme bénéficie d'un budget total de 18 millions de dollars auquel contribuent à part égale les deux paliers de gouvernement. Ce programme a pour raison d'être de faciliter le développement de nouvelles technologies qui favoriseront la conservation de l'énergie et l'exploitation des ressources énergétiques renouvelables. Parmi les objectifs importants du programme, mentionnons la sensibilisation du public, la découverte d'applications commerciales, la création de retombées économiques pour l'industrie manitobaine et la stimulation de l'emploi.

Cet essai avait pour objectif d'évaluer la rentabilité du carburol au Manitoba en comparant le rendement global et les coûts d'exploitation d'un parc-pilote fonctionnant au carburol avec ceux d'un parc de contrôle alimenté en essence sans plomb. Les fonds fournis au terme du CREDA se sont élevés à 129 000 $, tandis que la Société de téléphone du Manitoba a consenti pour sa part la somme de 60 250 $.

1.2 Le carburol employé pour alimenter les véhicules du parc-pilote était produit par la compagnie Mohawk Oil Ltd. et se composait à 10 p. 100 d'alcool éthylique et à 90 p. 100 d'essence Esso 2000 sans plomb. Les véhicules du parc de contrôle fonctionnaient uniquement à l'essence Esso 2000 sans plomb.

1.3 Le parc-pilote et le parc de contrôle étaient tous deux constitués de 25 véhicules choisis parmi les véhicules d'entretien du parc actuel de la Société de téléphone du Manitoba. La composition de ces deux parcs était identique quant à la nature des véhicules, allant des automobiles sous-compactes d'une masse de 760 kg aux fourgonnettes pesant 5 460 kg. Les cylindrées variaient de 1,57 litre à 5,74 litres.

1.4 L'essai s'est déroulé pendant 22 mois, période au cours de laquelle les véhicules du parc-pilote alimentés en carburol ont parcouru 7 500 km, alors que le parc de contrôle fonctionnant à l'essence sans plomb avait à son actif 1 000 000 de km.

1.5 Des analyses périodiques du carburant, effectuées tout au long de l'essai, ont démontré que la teneur du carburol en éthanol variait de 10,2 à 11,2 p. 100; la teneur en humidité allait de 0,01 à 0,14 p. 100 tandis que la pression de vapeur Reid oscillait de 97 à 103 kPa.

1.6 Les rendements conférés par l'essence et par le carburol ont été comparés par le biais de trois types d'essais distincts: 1. La souplesse générale de conduite et la consommation relative de carburant ont été établies grâce à des sondages auprès des conducteurs et à des données de consommation portant sur l'utilisation normale des véhicules en ville et à la campagne. 2. La consommation spécifique de carburant a été établie par des essais dynamométriques effectués sur des véhicules choisis et reproduisant des cycles de conduite type. 3. Les caractéristiques détaillées de fonctionnement ont été établies pour un moteur, utilisant les deux carburants, grâce à des essais dynamométriques du moteur et à des tests normalisés de rendement.

1.7 Les résultats des différents essais se présentent comme suit:

(a) Souplesse de conduite: Aucune différence n'a été remarquée dans la souplesse de conduite ni dans le rendement global des véhicules fonctionnant au carburol ou à l'essence. Les conducteurs des véhicules alimentés en carburol se sont dits satisfaits du comportement de leurs véhicules et ont signalé que le rendement restait essentiellement le même quelque soit le carburant employé. Dans la majorité des cas, les conducteurs étaient affectés aux mêmes véhicules avant et après la conversion au carburol. Enfin, aucun problème attribuable aux conditions météorologiques ne s'est manifesté sur les véhicules alimentés en carburol pendant toute la durée de la démonstration.

(b) Consommation comparée des deux parcs: Le carburol n'étant disponible qu'en quantité limitée durant la période d'essai, il a été décidé de déployer le parc de contrôle (essence) principalement à la campagne, et d'exploiter le parc-pilote (carburol) en ville surtout, plus précisément dans deux zones urbaines. Par conséquent, la comparaison des données de consommation globale des deux parcs n'était pas valable. Pour obtenir des résultats utilisables dans le cadre de l'essai, on a comparé la consommation spécifique de chacun des 25 véhicules du parc-pilote avec la consommation spécifique de ces mêmes véhicules au cours des 12 mois précédant leur conversion, c'est-à-dire lorsqu'ils fonctionnaient à l'essence. Dans les deux cas, les véhicules étaient exploités en ville. Cette comparaison a révélé qu'il n'y avait aucune différence sensible de consommation. Mais une analyse plus poussée a permis d'établir que la consommation spécifique de véhicules semblables était moindre lorsque ces derniers fonctionnaient au carburol. Cette différence, au niveau de confiance de 90 p. 100, variait de 2 à 107 MJ/100 km.

(c) Essais dynamométriques du véhicule: Les essais dynamométriques du véhicule, employés pour comparer le rendement de neuf véhicules différents alimentés en essence puis en carburol, se sont déroulés dans des conditions de charge simulant la conduite en ville à 48 km/h et la conduite sur route à 88 km/h. Cette façon de procéder a permis de supprimer les variables aléatoires qui faussent inévitablement les comparaisons entre parcs de véhicules et d'aboutir à une comparaison valable de la consommation spécifique de carburol de véhicules semblables fonctionnant au carburol et à l'essence, en ville et à la campagne. Les résultats étaient probants: la consommation spécifique de carburant était sensiblement moindre (niveau de confiance de 90 p. 100) dans le cas des véhicules fonctionnant au carburol en ville que dans celui des mêmes véhicules lorsqu'ils étaient alimentés à l'essence. En conditions simulées de conduite en ville, la consommation de carburol était inférieure de 1,7 p. 100 à la consommation d'essence, ce qui s'est traduit par une économie de 22 ¢/100 km si l'on admet un prix de 44 ¢/L pour les deux carburants. De même, en conditions simulées de conduite sur

l'autoroute, la consommation spécifique de carburant était sensiblement inférieure (niveau de confiance de 85 p. 100) dans le cas des véhicules fonctionnant au carburol que dans celui des mêmes véhicules lorsqu'ils étaient alimentés à l'essence. Ici, l'économie réalisée était de l'ordre de 1,5 p. 100.

(d) Essais dynamométriques du moteur: Dans le cadre d'essais dynamométriques comparés d'un moteur d'automobile classique de 2,3 L, le carburol a permis d'atteindre une puissance maximale supérieure de 7 p. 100 à celle réalisée avec l'essence. À la charge maximale, la consommation spécifique de carburant aux freins était jusqu'à 10 p. 100 inférieure avec le carburol qu'avec l'essence.

(e) Durabilité du moteur: Les moteurs alimentés en carburol exigaient le même entretien courant que les moteurs fonctionnant à l'essence, ni plus ni moins. Rien ne porte à croire que l'éthanol du carburol conduit à la détérioration des composants du circuit carburant. À l'issue des essais, le démontage et l'inspection de deux types de moteur fonctionnant au carburol et de deux moteurs semblables alimentés en essence ont permis de constater qu'il n'y avait aucune différence quant à l'usure des pièces.

1.8 Il ressort de tous ces essais que le carburol constitue un combustible de remplacement tout à fait viable. Si le carburol se vendait au même prix que l'essence, il est probable que la conversion au carburol permettrait à un exploitant de parc de véhicules de réaliser des économies de l'ordre de 1 à 2 p. 100 sur les coûts d'exploitation.

2.0 INTRODUCTION

This fleet test was conducted by the Manitoba Telephone System under a joint contract from the Canadian Department of Energy, Mines and Resources and the Manitoba Department of Energy and Mines through the Manitoba/Canada Agreement for the Development and Demonstration of Renewable Energy and Energy Conservation Technologies. The Industrial Technology Centre/Manitoba Research Council was retained as the technical consultant, providing project supervision, data analyses, testing services and report preparation.

The objective of the test was to assess the feasibility of gasohol as an automotive fuel in Manitoba by comparing the overall performance and operating costs of a test fleet operating on gasohol with that of a control fleet operating on Esso 2000 unleaded gasoline. The large variations in temperature and climatic extremes, typical to Manitoba, make it an ideal location for this type of fuel comparison testing.

The gasohol[1] used in this test was supplied by Mohawk Oil Co. Ltd. and was a blend of 10% ethyl alcohol and 90% Esso 2000 unleaded gasoline. The ethyl alcohol used in the blend was produced by Mohawk Oil Co. Ltd. at their facility in Minnedosa, Manitoba. No engine or fuel system modifications are needed when using this type of blend in a standard gasoline fueled vehicle.

Test vehicles were selected from the existing Manitoba Telephone System fleet of service vehicles. The gasohol powered test fleet and the gasoline powered control fleet each consisted of 25 similar vehicles ranging from subcompact automobiles with a mass of 760 kg to panel trucks with a mass of 5460 kg. Corresponding engine displacements varied from 1.57 to 5.74 L.

The gasohol fleet demonstration was initiated February 1, 1981. Original plans were to run the demonstration for two winters, however, by agreement of the project funding partners and Manitoba Telephone System, the demonstration was discontinued November 30, 1982. At termination, gasohol was being distributed in Manitoba by Mohawk Oil Co. Ltd. and was in widespread use by the general public. Manitoba Telephone System was also satisfied with the performance of gasohol in their vehicles and could see no purpose in continuing the demonstration.

Several significant test program changes were initiated by the program advisory committee during the test, as a result of ongoing test results and recommendations from the technical consultant. Original program plans were to utilize fuel consumption data from the two fleets in actual operation to

---

1 Gasohol is a blend of unleaded gasoline and ethanol, with ethanol concentration of 10% of more. In this study all tests were conducted with an ethanol concentration of 10% by volume.

compare specific fuel consumption. The large data scatter, typically associated with field tests, as a result of many uncontrolled variables, invalidated this type of fuel consumption comparison. It was therefore concluded that fleet data were valid only for general driveability comparisons. Specific fuel consumption comparisons were conducted in two ways: Historic fuel consumption data on gasoline fleet vehicles, when operated on gasoline, prior to conversion, were used to permit field use comparisons on the same vehicles with gasohol and gasoline. Finally, specific fuel consumption comparisons were conducted by utilizing a chassis dynamometer in controlled conditions with the vehicles subjected to simulated urban and highway driving cycles. This test permitted valid, statistically sound, fuel consumption comparisons.

During the 22 month test period, the gasohol test fleet travelled a cumulative distance of about 750,000 km while the gasoline control fleet travelled about 1,000,000 km. This report summarizes the results of all work conducted during the test period and details test procedures as well as modifications to procedures needed to meet program objectives. It also describes methods of data analysis needed to determine the significance of relatively small differences in performancce of the two fleets and recommends procedures that should be considered as key components of future fuel comparison testing. Due to the large amount of raw data collected only representative data samples or summary tables are included in this report.

3.0 SCOPE AND OBJECTIVES

3.1 Objectives

The overall objectives of the fleet test were as follows:

(a) To assess the driveability and overall performance of automotive vehicles operated on gasohol, in Manitoba driving conditions, relative to the performance of similar vehicles operated on gasoline.

(b) To compare the specific fuel consumption and operating costs of fleets of similar vehicles operating on gasohol and gasoline.

3.2 Scope of Work

The following work was conducted to achieve program objectives:

(a) During the initial test period, blending techniques were developed to produce gasohol from chemical grade ethanol and unleaded gasoline. This was necessary since the Mohawk Minnedosa distillery was not in operation during the first five months of testing. During the last 17 months of fleet testing, the ethanol used in the gasohol blend was produced at the Mohawk Minnedosa distillery.

(b) Chemical analysis techniques were developed for periodically determining the ethanol content and the water content of the gasohol test fuel. Ethanol content, water content, Reid vapor pressure and ASTM distillation characteristics of the gasohol supply were determined periodically throughout the test.

(c) Throughout the tests, vehicle performance data were analyzed with the MAINSTEM[2] data analysis system.

(d) Statistical techniques were developed for ongoing performance comparison of the gasohol and control fleets. These included comparisons of specific fuel consumption[3] and specific energy consumption[4] of the gasohol fleet with that of paired vehicles in the control fleet and with historic data on the gasohol vehicles prior to conversion to gasohol. Paired significance tests were also conducted on chassis dynamometer data comparing vehicle performance on gasoline and gasohol.

---

2 MAINSTEM Data System, Willowdale, Ontario. MAINSTEM is a commercial, computer-based accounting system for compilation and simple analysis of fleet performance data.

3 Specific fuel consumption is defined as the fuel consumed per unit distance and is reported in L/100 km.

4 Specific energy consumed is the energy consumed per unit distance and is reported in MJ/100 km.

(e) Engine dynamometer tests were conducted comparing the performance of a conventional 2.3 L automotive engine on gasohol and gasoline. Two series of tests were conducted, the first with gasohol blended from chemical grade ethanol and unleaded gasoline and the second with ethanol, produced at the Mohawk Minnedosa distillery and blended with Esso 2000 unleaded gasoline.

(f) Nine representative vehicles from the gasohol fleet were tested on a chassis dynamometer utilizing simulated urban and highway driving cycles. Tests were conducted with the same vehicles fueled alternately with gasoline and gasohol to enable fuel consumption comparisons in similar controlled driving conditions.

(g) The compatibility of standard fuel system components with gasohol was evaluated. In addition, at the completion of the test, two similar engines from each of the gasohol and control fleets were disassembled and inspected to assess relative engine durabilities for the two fleets.

(h) Throughout the test period, general vehicle driveability was evaluated by having all operators of the gasohol and control fleets complete a daily vehicle performance sheet. Driveability assessments were based on analysis of vehicle data sheets as well as vehicle service history records maintained by Manitoba Telephone System.

(i) During the test, work was initiated to formulate a base gasoline which, when blended with Mohawk ethanol, would produce a gasohol with vapor pressure similar to that of standard unleaded gasoline. This optimized gasohol was intended to reduce the possibility of fuel system vapor lock. This project was subsequently abandoned when the Co-op Refinery, Regina, Saskatchewan, discontinued supply of the various gasoline fractions which were to be used for blending with ethanol. The reason for this discontinuation was the cancellation of a proposed grain ethanol plant in Saskatchewan in the fall of 1982. Co-op Refinery was hopeful that they could use these results in the formulation of an optimized gasohol for Saskatchewan distribution. Since no vapor lock problems occurred with gasohol vehicles during the test, it was decided not to pursue the matter any further.

4.0 METHODS AND TEST PROCEDURES

4.1 Fleet Vehicle Selection and Operation

The demonstration fleet consisted of 50 vehicles selected from the Manitoba Telephone System fleet of service vehicles. The fleet was composed of a variety of vehicles, varying from subcompact automobiles with a mass of 760 kg to panel trucks with a mass of 5460 kg. Engine displacements varied from 1.57 to 5.74L. All vehicles were brought up to manufacturer's specifications by MTS personnel prior to program initiation. The gasohol vehicles required no modification other than being fueled with gasohol.

An attempt was made to match 25 gasoline vehicles with 25 identical gasohol vehicles. Due to vehicle availability and MTS service priorities this was impractical. Only eighteen pairs of vehicles could be obtained for the two fleets. The remaining seven vehicles in each fleet were not matched with similar vehicles in the other fleet. A description of fleet vehicles is given in Tables 1 and 2.

The gasohol fleet was operated in Winnipeg due to the unavailability of gasohol in rural areas. For logistic reasons, the control fleet was operated in rural Manitoba communities. Since, the gasohol fleet was operated in urban conditions and the control fleet was operated primarily in rural conditions, resulting data were valid only for driveability comparison and could not be used for comparisons of specific fuel consumption. Specific fleet fuel consumption comparisons were made utilizing historic data for the gasohol fleet. The gasohol vehicles had all been operated on gasoline, in similar urban driving conditions, prior to being converted to gasohol.

4.2 Driveability Assessment

Log sheets (Figure 1) were distributed to the fleet drivers. Vehicle operators were required to submit the log sheets on a weekly basis. Information collected from these sheets included distance travelled, amount of fuel consumed and the following list of driveability assessment factors:

1) The amount of cranking required to start engine
2) Stalling after starting
3) Stalling in traffic
4) Idle roughness
5) Hesitation, bucking or coughing
6) Lack of power
7) Pinging
8) Dieseling

Driveability data were tabulated to compare relative driveability of the two fleets.

Table 1. Matched Fleet Vehicles

Vehicle Type	Year	Model	Vehicle Mass (kg)	Engine Displacement (L)	Number of Cylinders	Transmissions	Fuel
1	1978	Ford Fiesta	758	1.57	4	Standard	G,C
2	1980	Mercury Zephyr Wagon	1310	2.29	4	Standard	G,C
3	1979	AMC Concord Wagon	1294	3.80	6	Automatic	G,C
4	1978	Ford Fairmont Wagon	1310	3.28	6	Automatic	G,C
5	1980	Ford Fairmont Wagon	1310	3.28	6	Standard	G,C
6A	1979	Ford Van	2520	4.92	6	Standard	G,C
6B	1979	Ford Van	2520	4.92	6	Standard	G,C
7	1980	Ford Van	2520	4.92	6	Standard	G,C
8	1979	Chevrolet Blazer	2747	4.10	6	Standard	G,C
9	1980	Ford Pick-Up	2747	4.92	6	Automatic	G,C
10	1980	Dodge Pick-Up	3405	3.69	6	Standard	G,C
11	1978	Chevrolet Van	2542	5.00	8	Automatic	G,C
12	1979	IHC Scout	2767	4.98	8	Automatic	G,C
13	1980	Chevrolet Van	2815	5.74	8	Standard	G,C
14	1979	Dodge Pick-Up	3405	5.21	8	Standard	G,C
15	1978	Chevrolet Van	3587	5.74	8	Automatic	G,C
16	1979	Chevrolet Van	3587	5.74	8	Automatic	G,C
17	1978	Dodge Karry Van	4540	5.21	8	Automatic	G,C

G - gasohol fuelled (test fleet)
C - gasoline fuelled (control fleet)

Table 2. Unmatched Fleet Vehicles

Vehicle Type	Year	Model	Vehicle Mass (kg)	Engine Displacement (L)	Number of Cylinders	Transmissions	Fuel
18	1979	AMC Concord Wagon	1294	3.28	6	Standard	G
19	1980	Ford Fairmont Wagon	1310	3.28	6	Automatic	G
20	1980	GMC Vandura Van	2747	4.10	6	Standard	G
21	1980	Dodge Pick-Up	3405	3.69	6	Standard	G
22	1979	Chevrolet Pick-Up	3405	5.00	8	Automatic	G
23	1978	Chevrolet Step Van	5448	5.74	8	Automatic	G
24	1979	Chevrolet Step Van	5448	5.74	8	Standard	G
25	1979	AMC Concord Wagon	1294	4.23	6	Automatic	C
26	1980	Ford Fairmont Wagon	1310	3.28	6	Standard	C
27	1980	Dodge Pick-Up	2747	3.69	6	Automatic	C
28	1979	Chevrolet Pick-Up	3405	5.74	8	Automatic	C
29	1979	Chevrolet Van	3587	4.10	6	Standard	C
30	1979	Chevrolet Step Van	5448	5.74	8	Standard	C
31	1980	Chevrolet Step Van	5448	5.74	8	Standard	C

G - gasohol fuelled (test fleet)
C - gasoline fuelled (control fleet)

MANITOBA TELEPHONE SYSTEMS - MANITOBA RESEARCH COUNCIL
GASOHOL - FLEET TEST

Daily Log Sheet

Vehicle No. _____ Type _____ Date _____

Vehicle Base Location _____ Driver's Name _____

Daily Distance

End: km _____

Starting: km _____

Services

Fuel Add:
L _____ Odomoter _____

Oil: # L _____

Tire Pressures

(Please check at least once a week)

Left Front _____ Right Front _____

Left Rear _____ Right Rear _____

Maintenance Required: Yes ___ No ___

Was vehicle refueled with other than test fuel? Yes _____ No _____. If Yes, please give fuel type and reason in Other Comments below.

Did you have problems with any of the following: If so, indicate severity.

	Mildly Annoying	Very Troublesome
1) Cranking required to start engine		
2) Stalled after starting		
3) Stalls in traffic		
4) Idle roughness		
5) Hesitation, bucking or coughing		
6) Lack of power		
7) Pinging		
8) Dieseling		

Regardless of severity, if any problems occurred, please describe (1) type of driving, (2) time of occurence, and (3) approximate ambient temperature for each problem occurrence. _____

_____

_____

Other comments: _____

_____

Figure 1. Daily Log Sheet for Completion by Fleet Drivers

4.3 Fuel Analyses

The test fuels were analyzed on a periodic basis. They were tested for alcohol content, moisture content and vapor pressure. Distillation curves were also determined.

The ethanol content was determined by the use of specially developed gas chromatographic procedure. This technique, described in Appendix 1, is both qualitative and quantitative and can be adapted for the determination of other alcohols in gasoline.

Moisture content was determined using the Karl Fischer amperometric titration according to the American Society for Testing Materials procedure ASTM D1744.

The Reid vapor pressure was determined according to the procedure outlined in ASTM D323, while distillation curves were determined according to the procedure outlined in ASTM D86.

4.4 Engine Dynamometer Test

Enging dynamometer testing, comparing performance with gasohol and gasoline fuels, was conducted at the Winnipeg facility of K-Cycle Engines Ltd. The tests were performed using a 2.3L, four cylinder Ford Fairmont engine, according to Society of Automotive Engineers SAE J816b.
Two series of dynamometer tests were performed. The first test compared engine performance with gasohol prepared from chemical grade ethanol and spring grade Esso 2000 regular unleaded gasoline to performance with winter grade Esso 2000 regular unleaded gasoline.

The second test compared engine performance with winter grade Esso 2000 gasoline to performance with gasohol prepared from the winter grade Esso 2000 and Mohawk produced ethanol.

4.4.1 Test Procedures

The engine was set to the manufacturer's operating specifications. The engine was then operated at a speed of 1000 rpm with fuel flow and other parameters measured at torques of 27,54, 81 and 108 N.m. The speed was then incremented in 500 rpm steps and the sets of measurements repeated, until a speed of 4500 rpm had been reached.

The following parameters were monitored and recorded for each speed and torque setting:

Fuel Flow
Manifold Vacuum
Ambient Air Temperature
Fuel Supply Temperature

Coolant Outlet Temperature
Coolant Inlet Temperature

Engine load and fuel consumption data points were the average of two stabilized sustained values which did not vary by more than 1% and which were measured over intervals from 0.5 to 2 minutes, each.

4.5 Chassis Dynamometer Tests

Chassis dynomometer tests, comparing the performance of the same vehicles on both gasoline and gasohol were performed on a Sun Road-A-Matic chassis dynamometer at the Manitoba Telephone System test facility. Two test speeds (48 and 88 km/h) were used in the comparison. These speeds were chosen as they approximately simulated city and highway driving conditions and are also those recommended in the Sun specification manual.

The test at 48 km/h was characterized by a load producing a gauge pressure of -18.75 kPa at the intake manifold. At this condition, the throttle is sufficiently open to cause enough enrichment for cylinder pressure to be near maximum. This simulates city driving where a large proportion of the driving is acceleration and deceleration.

The test at 88 km/h was characterized by a load producing a gauge pressure of -57.2 kPa at the intake manifold. This is equivalent to cruising on a level road. Under these conditions the air/fuel mixture is lean and cylinder pressure is near minimum.

4.5.1 Test Procedure

Nine gasohol test vehicles were converted to unleaded gasoline by installing a fuel line to an outboard gasoline container. Testing proceeded only after the engine oil temperature had reached the minimum operating temperature. The intake manifold pressure was used to determine the power condition at each test speed. The settings were gauge pressures of -18.75 and -57.2 kPa at 48 and 88 km/h, respectively. Once the power setting had been determined for a vehicle, subsequent manifold pressure readings were disregarded. The test fuels were Esso 2000 unleaded gasoline and gasohol blended from Esso 2000 unleaded gasoline and Mohawk Minnedosa ethanol.

The test used three different vehicle operators. To ensure consistency only one operator ran tests on any individual vehicle.

Esso 2000 gasoline was used to determine the power settings for each vehicle and was the first fuel tested. Each vehicle was run for 0.8 km at constant speed and power. The test was repeated 10 times at each test speed with fuel consumption recorded at the completion of

of each run. The same procedure was repeated for gasohol using the same speeds and power settings determined by the gasoline tests. High gear was used for all tests.

Two different operating procedures were used. In the first procedure the test vehicle speed was alternated between 48 and 88 km/h for each subsequent test. In the second procedure, all replicates at 48 km/h were completed before running tests at 88 km/h. The second procedure was found to be less prone to error due to more stable operating conditions.

4.6 Fuel System Compatibility

Comparative testing was done to determine the long term effects of gasohol and gasoline on fuel system components. Carburetor floats were used in this study.

4.6.1 Test Procedures

The carburetor floats used were Delco part number 17056073. Two sets of three floats were placed in 500 mL glass containers with Teflon coated lids, filled with gasohol and Esso 2000 gasoline respectively. The containers were stored at room temperature (22 + 3°C) for 90 days. The floats were then blown dry in a stream of air, and weighed in sealed weighing vessels, so that any absorbed fuel would register as a mass change. The mass and density of the floats were determined both before and after immersion. The test fuels were characterized using the test procedures in clause 4.3

4.7 Engine Durability

At test completion two pairs of similar engines from each fleet were dissasembled and inspected for comparative wear. One set was 6 cylinder, 4.92 L Ford engines, while the second set was 6 cylinder, 3.80 L AMC Concord engines.

4.8 Data Analysis

4.8.1 MAINSTEM Data Collection System

MAINSTEM is a commercial, computer-based accounting system for the compilation and simple analysis of fleet data. It is generally used by fleet managers to track fleet costs and vehicle maintenance. This system was used for monitoring the fuel consumption of the gasohol and control fleets.

4.8.2 Paired Significance Tests

Initial attempts to compare fuel consumption data from the two fleets were rejected as statistically unacceptable since the gasohol fleet was operated primarily in an urban environment and the gasoline fleet was operated primarily in a rural environment.

Therefore the fuel consumption data collected for the gasohol fleet were compared with historic data for the same vehicles. Historic data were based on 12 months of operation of the same vehicles in urban driving before conversion to gasohol. The vehicles were used in similar operating and climatic conditions (Table 3). In this manner, it was possible to compare the performance of identical vehicles with two different fuels under relatively similar operating conditions.

A paired significance test was performed with the above data[5,6]. The data were also analyzed for possible relationships between energy consumption and vehicle mass, using a simple regression analysis procedure.

Similar paired significance tests were also performed comparing specific fuel consumption data from the chassis dynamometer tests. This analysis permitted a valid comparison of specific fuel consumption due to the controlled nature of the testing.

---

5 SAE SP-63/250. White, John S., "Significant Difference", in Statistics for the Engineer, (Warrendale, PA: Society of Automotive Engineers, Incl. 1980), pp 14 - 26.

6 Mendenhall, William, Introduction to Probability and Statistics, (Belmont, California, Duxbury Press, 1971).

5.0 RESULTS AND DISCUSSION

5.1 Driveability

Driveability results accumulated from daily driver log sheets, for the gasohol fleet, are given in Figure 2. In summary 5.5% of the drivers reported difficulty with poor engine starting, stalling, rough idling, hesitation and bucking and a lack of engine power. Stalling in traffic and dieseling (run-on) were reported by 3.6% of the drivers. Engine pinging was reported by 1.8% of the drivers. These results are comparable to results obtained from drivers operating on regular unleaded gasoline and are a reflection of vehicle type and maintenance and not of fuel type. Although a comparable driveability reporting system was not maintained for the control fleet, fleet operators indicated that driveability and overall performance of the gasohol powered vehicles was similar to that of gasoline powered vehicles. Generally, the drivers operating the gasohol vehicles were the same ones who operated the same vehicles before conversion from gasoline to gasohol.

No major problems were apparent. Plugging of several fuel filters and sticking of the throttle mechanism occurred on three gasohol powered vehicles.

5.2 Fuel Analyses

Periodic fuel analyses indicated that the ethanol content of the test fuel ranged from 10.2 to 11.2% by volume. The results are shown in Figure 3.

Moisture content of the test fuel varied from 0.01 to 0.14% (Figure 4) indicating that phase separation was not a problem. It was determined that it was important to keep the gasohol moisture content below 0.2% to prevent phase separation.

Reid vapour pressure for the gasohol test fuel (Figure 5) varied from 97 to 103 kPa during the winter months due to the addition of butane. During the summer months it varied from 74 to 87 kPa.

Figure 6 presents comparative ASTM distillation curves for Mohawk gasohol and Esso 2000 unleaded gasoline. The distillation curve for gasohol is noticeably lower than for gasoline. The increased front end volatility presents a potential for fuel system vapour lock in hot weather. This was not, however, reported as a problem during the tests.

During the first test phase (March 1 to July 1, 1981) the gasohol test fuel was formulated from chemical grade ethanol and unleaded gasoline. This was necessary since ethanol produced by the Mohawk Minnedosa distillery was not yet available. When the ethanol from the distillery was incorporated into the test program, fleet operators did not notice any difference in vehicle operation. During the first phase, the total operating distance was 120,000 km for the gasohol fleet and 166,500 km for the gasoline fleet.

Table 3 presents Winnipeg summer and winter temperature data from June, 1980 to August, 1982. This includes the period during which historic fleet data were used (February, 1980 to February, 1981) as well as the period during which gasohol fleet data were collected (March, 1981 to November, 1982). No weather related problems were encountered with gasohol powered vehicles.

Table 3: Monthly Summer and Winter Temperatures in Winnipeg

Month/Year	Maximum Mean (°C)	Minimum Mean (°C)	Maximum Extreme (°C)	Minimum Extreme (°C)
12 Months before Conversion				
June 1980	24.0	9.6	34.4	0.8
July 1980	27.3	13.5	34.8	5.5
August 1980	22.5	11.3	30.7	3.5
December 1980	-10.3	-20.6	6.4	-30.3
January 1981	-8.4	-19.7	2.0	-31.8
February 1981	-5.5	-14.7	7.5	-31.0
Gasohol Operation				
June 1981	22.3	9.6	27.5	4.7
July 1981	26.8	13.7	34.0	5.6
August 1981	26.6	13.6	18.7	7.8
December 1981	-9.0	-16.8	0.4	-31.3
January 1982	-19.9	-30.4	-3.6	-38.9
February 1982	-9.5	-19.5	6.0	-34.0
June 1982	20.6	6.5	27.1	-1.0
July 1982	26.0	14.0	31.1	8.4
August 1982	23.0	10.6	29.5	0.7

5.3 Engine Dynamometer Tests

In the first series of dynamometer tests, engine performance on gasohol, blended from chemical grade ethanol and spring grade ESSO 2000 gasoline, was compared with performance on winter grade ESSO 2000 gasoline. The only significant differences in engine performance in this series was that gasohol resulted in slightly higher fuel consumption compared to

gasoline. The maximum torque produced with gasohol was slightly lower than the torque produced with gasoline. These results were consistent with the lower energy content of gasohol (32 MJ/L for gasohol as compared to 33.8 MJ/L for gasoline) but were inconclusive because the base gasoline in the gasohol was not the same as the gasoline used for comparison. A second series of dynamometer tests was run in which the base gasoline in the gasohol was the same grade as the comparison gasoline. In this series, the gasoline was winter grade ESSO 2000 regular unleaded and the gasohol was a blend of ethanol from the Mohawk distillery at Minnedosa and ESSO 2000 winter grade regular unleaded gasoline.

Only slight differences in engine performance were apparent when comparing the two fuels. Differences in brake specific fuel consumption between gasohol and gasoline were generally less than the inherent variability in brake specific fuel consumption for a typical automotive engine indicating that no difference would likely be noticed in normal operation. Considering that gasohol has 4% less energy per unit mass than gasoline and 3% less energy per unit volume than gasoline, this indicated that gasohol was a relatively more efficient fuel than gasoline.

This relatively higher efficiency can possibly be attributed to the fact that the air/fuel mixture is somewhat leaner when gasohol is introduced through a carburetor set for gasoline. Ethanol has a stoichiometric air/fuel ratio of nine on a volume basis, while gasoline has a stoichiometric air/fuel ratio of 15. The stoichiometric air/fuel ratio for the test gasohol is therefore 14.5. Since the carburetor should deliver essentially the same air/fuel ratio with both fuels, the gasohol air/fuel mixture is effectively 3% leaner. Fuel efficiency normally increases with leaner mixtures.

The maximum power output with gasohol was about 7% higher than with regular unleaded gasoline. Gasohol did not require as much enrichment as regular unleaded gasoline to develop maximum power. Maximum load brake specific fuel consumption was about 10% lower with gasohol than with gasoline. Figure 7 presents a typical plot of brake specific fuel consumption as a function of engine torque for both fuels. Additional engine test results are presented in Appendix 2.

The hydrocarbon (HC) and carbon monoxide (CO) exhaust emissions were determined with a Sun analyzer sampling after the catalytic converter. The HC readings were about the same for both fuels.The CO readings were generally lower with gasohol than with gasoline, especially at maximum loads. No meaningful comparison on NO_x emissions could be made from the few Drager tube readings that were taken.

5.4 Fleet Performance Comparisons

5.4.1 Specific Fuel Consumption Comparison- Paired Historic Fleet Data

Average specific fuel consumption data for the gasohol fleet vehicles, during the 22 month test period, were compared with historical fuel consumption data for the same vehicles operating on gasoline during the twelve months prior to conversion. Statistical testing was based on the difference between fuel consumption values, for each data pair, taken as gasoline consumption less gasohol consumption. Positive differences indicate a volume saving in fuel consumption using gasohol. Table 4 summarizes these comparisons. Vehicle types may be determined by referring to Tables 1 and 2.

A two-tailed paired difference significance test (Appendix 3) performed on the data yielded a 't' value of 0.54. At the 90% confidence level, for the mean gasohol consumption to be significantly different than the mean gasoline consumption, the calculated 't' value must fall outside the range of -1.71 to +1.71. Consequently, the results reported in Table 4 indicate no significant difference in mean specific fuel consumption between the two paired fleets.

The above specific fuel consumption data were converted to specific energy consumption by using gross heats of combustion, determined using an oxygen bomb calorimeter. Gasoline had a gross heat of combustion of 33.81 MJ/L compared to 32.22 MJ/L for gasohol.

A one-tailed paired difference significance test performed on the specific energy consumption data (Table 5), yielded a 't' value of 1.71, compared to the required minimum value of 1.32 for significance at the 90% confidence level. These results indicate that the gasohol vehicles consumed significantly less energy than the gasoline vehicles. Consequently, the results indicate that gasohol is a more energy efficient fuel than gasoline. A 90% confidence level for the difference between energy consumption ranged from 2 to 107 MJ/100km.

5.4.2 Specific Fuel Consumption Comparisons - Gasohol and Gasoline Control Fleet

Average fuel consumption data for the gasohol fleet was compared with data from the control fleet. Only a total of 18 pairs of matched vehicles (Table 1) were used for this comparison. The remaining vehicles in the two fleets could not be matched and therefore, were not valid for inclusion in the statistical analysis. Statistical analysis was based on the average difference between specific fuel consumption for each data pair, taken as the consumption of gasoline

Table 4. Mean Fuel Consumption of the Gasohol Fleet Vehicles Compared With Mean Fuel Consumption of the Same Vehicles Operated on Gasoline Prior to Conversion

Vehicle Type (See Tables 1&2)	Specific Fuel Consumption (L/100 km)		
	Gasoline	Gasohol	Difference
1	10.42	10.61	-0.19
2	15.55	15.53	0.02
3	18.17	18.10	0.07
4	15.39	13.80	1.59
5	16.38	14.68	1.70
6A	22.93	16.22	6.70
6B	25.37	22.79	2.59
7	22.47	16.16	6.31
8	22.29	18.90	3.39
9	21.49	22.43	-0.94
10	22.50	20.55	1.95
11	31.78	22.47	9.31
12	25.43	24.06	1.38
13	26.90	38.78	-11.89
14	22.86	24.70	-1.84
15	29.09	39.86	-10.77
16	23..63	26.50	-2.87
17	37.71	35.00	2.71
18	19.59	24.56	5.03
19	10.31	16.15	-5.84
20	22.83	17.21	5.62
21	20.84	18.20	2.64
22	24.09	26.80	-2.71
23	39.62	41.09	-1.47
24	37.20	36.41	0.79

$t_{calculated} = 0.54$

$t_{90,24} = \pm 1.71$

Table 5. Mean Energy Consumption of the Gasohol Fleet Vehicles Compared with Mean Energy Consumption of the Same Vehicles Operated on Gasoline Prior to Conversion

Vehicle Type (See Tables 1&2)	Specific Energy Consumption (MJ/100km)		
	Gasoline	Gasohol	Difference
1	352.23	341.82	10.41
2	525.81	500.41	25.40
3	614.19	538.18	31.01
4	520.34	444.64	75.70
5	553.67	472.96	80.72
6A	775.16	522.74	252.42
6B	857.79	734.13	123.66
7	759.71	520.58	238.13
8	753.73	608.96	144.77
9	726.64	722.73	3.92
10	760.86	662.12	98.74
11	1074.48	723.98	380.50
12	859.82	775.08	84.74
13	909.35	1249.56	-340.20
14	772.80	795.83	-23.04
15	983.40	1284.16	-300.76
16	799.03	853.83	-54.80
17	1275.08	1127.70	147.38
18	662.24	469.16	193.08
19	348.51	520.35	-171.84
20	771.75	554.35	217.40
21	704.47	586.24	118.22
22	814.58	863.50	-48.91
23	1339.38	1323.86	15.53
24	1257.73	1173.19	84.54

t calculated = 1.71

$t_{90,24}$ = 1.32

less the consumption of gasohol. Positive differences would indicate a volume saving in fuel consumption using gasohol. Tables 6 and 7 present results for specific fuel consumption and specific energy consumption, respectively for both the control and gasohol fleets.

A two-tailed paired difference significance test performed on the data (Table 6), yielded a 't' value of -1.47. At the 90% confidence level for mean gasohol consumption to be significantly different than the mean of gasoline consumption, the calculated 't' value must fall outside the range -1.75 to +1.75. Therefore, although the specific fuel consumption of gasohol fleet was slightly greater than that of gasoline fleet due to different operating conditions, the difference was not significant.

Converting the fuel consumption data into specific energy consumption (Table 7), and performing a one-tailed significance test, resulted in a 't' value of -0.78, compared to the required minimum value of 1.34 for significance of the 90% confidence level. This indicated that there was no significant difference in specific energy consumption for the gasohol and control fleets.

These results from the control fleet contradict the results obtained using historic fleet data. This is to be expected as the control fleet was operated in rural areas while the gasohol fleet was operated in urban areas. This inconsistency in test procedure was as a result of the unavailability of gasohol outside Winnipeg during the demonstration period.

During the initial test period fuel consumption data were analyzed using simple regression analyses. The linear regressions of specific fuel consumption as a function of vehicle mass were compared for both the control fleet and the gasohol fleet. Although these analyses, in some cases, produced significant coefficients of linear regression, the wide scatter of data made this an ineffective method of comparing fuel consumption of the two fleets. Specific fuel consumption is dependent on the aerodynamic configurations and many other variables in addition to vehicle mass. None of the regression comparisons are included in this report.

5.5 Chassis Dynamometer Tests

Table 8 lists the vehicles used in the chassis dynamometer comparison tests.

Results for simulated urban driving at 48 km/hr are reported in Table 9. Using a one-tailed paired significance test, the specific fuel consumption of these vehicles operating on gasohol was significantly less than when operating on gasoline, at the 90% confidence level. Based on a distance of 100 km travelled, the nine vehicles tested consumed 301.7 L of gasoline compared to 296.6 L of gasohol. This represents a 1.7% savings in fuel consumed if gasohol is used in place of gasoline.

Table 6. Mean Specific Fuel Consumption Comparison of the 17 Matched Fleet Vehicles in the Gasohol and Control Fleets

Vehicle Type (See Table 1)	Specific Fuel Consumption (L/100km)		
	Gasoline Control Fleet	Gasohol Fleet	Difference
1	9.04	10.61	-1.57
2	10.48	15.53	-5.05
3	12.94	18.10	-5.16
4	12.84	13.80	-0.96
5	12.88	14.68	-1.80
6A	21.89	19.50	2.39
6B	21.89	19.50	2.39
7	27.21	16.16	1.06
8	15.82	18.90	-3.08
9	28.88	22.43	6.45
10	17.70	20.55	-2.85
11	20.03	22.47	-2.44
12	33.28	24.06	9.22
13	20.04	33.78	-18.74
14	20.14	24.70	-4.56
15	32.22	33.18	-0.96
16	24.72	26.50	-1.78
17	22.76	35.00	-12.24

t calculated = -1.47

$t_{90,17} = \pm 1.75$

Table 7. Mean Specific Energy Consumption Comparison of the 17 Matched Fleet Vehicles in the Gasohol and Control Fleets

Vehicle Type (See Table 1)	Specific Energy Consumption (MJ/100 km)		
	Gasoline Control Fleet	Gasohol Fleet	Difference
1	305.74	341.85	-36.11
2	354.33	500.41	-146.08
3	437.47	583.18	-145.71
4	434.12	444.64	-10.52
5	435.54	472.96	-37.42
6A	740.10	628.42	111.68
6B	740.10	628.42	111.68
7	581.97	520.58	61.39
8	534.74	608.96	-74.22
9	976.40	722.73	253.67
10	598.37	662.12	-63.75
11	1010.11	1004.07	6.04
12	1125.03	775.08	349.94
13	677.48	1249.56	-572.07
14	680.90	795.83	-114.93
15	1010.11	1004.07	6.04
16	835.82	853.83	-18.01
17	769.52	1127.70	-358.18

t calculated = -0.78

$t_{90,16}$ = 1.34

Table 8. Description of Test Vehicles

Vehicle Type	Year	Model	Test Mass (kg)	Engine Displacement (L)	Number of Cylinders	Transmission
A	1978	Ford Fiesta	894	1.57	4	4 Speed Standard
B	1979	AMC Concord Sedan	1430	3.80	6	3 Speed Automatic
C	1980	Ford Station Wagon	1446	3.28	6	3 Speed Standard
D	1979	Ford Van	1723	4.92	6	3 Speed Automatic
E	1980	Ford Pick-Up	1773	4.92	6	3 Speed Automatic
F	1979	Dodge Pick-Up	1826	5.21	8	4 Speed Standard
G	1978	Chevrolet Van	1866	5.76	8	3 Speed Automatic
H	1978	Dodge Van	2394	5.21	8	3 Speed Automatic
I	1979	Chev Step Van	2812	5.76	8	4 Speed Automatic

Table 9. Chassis Dynamometer Results for 48 km/h (Simulated Urban Driving)

Vehicle Type (See Table 8)	Specific Fuel Consumption (L/100km)			
	Gasoline	Gasohol	Difference (di)	di^2
A	24.93	25.93	-1.00	0.990
B	18.23	18.03	0.20	0.041
C	17.82	18.22	-0.41	0.164
D	18.18	16.77	1.41	1.997
E	23.11	23.59	-0.48	0.228
F	27.46	27.61	-0.16	0.024
G	25.12	24.92	0.20	0.038
H	43.71	40.98	2.73	7.469
I	52.14	51.13	1.02	1.032
J	50.98	49.43	1.55	2.409
	301.68	296.60	5.08	14.391

t calculated = 1.40

$t_{90.9}$ = 1.38

In simulated highway driving at 88 km/h (Table 10) the specific fuel consumption was, once again, less when operated on gasohol than when operated on gasoline. In this case, differences were significant at the 85% confidence level. Average gasohol consumption was 1.5% less than gasoline consumption.

The chassis dynamometer allowed a high degree of standardization to be achieved by the elimination of uncontrolled variables. The controlled and reproducible conditions allowed the two fuels to be more accurately compared than in actual road tests. The results show that there is a small economic advantage for a fleet operator to use gasohol.

5.6 Fuel System Compatibility

Results of long term immersion tests of carburetor floats in gasohol and gasoline were as follows: density determinations of floats immersed in gasohol and gasoline showed an average density increase of 0.44% from gasohol and 0.57% from gasoline. The masses of similar floats immersed gasohol and gasoline increased by 0.37 and 0.43%, respectively. The average volumetric increases of the floats were 0.17% in gasohol and 0.6% in gasoline. In each case, the increase in mass included a small amount of fuel absorbed into the float.

The distillation data for the test fuels used for long term immersions are presented in Appendix 4. Some loss of low boiling components was noted with both fuels. The ethanol content of the gasohol increased from 10.35 to 10.62% over the immersion period. This could be explained by evaporative losses.

Although the sample size was small, it can be concluded that the long term effects of gasohol on carburetor floats were no worse than those of gasoline. In addition, no evidence of corrosion due to ethanol in the gasohol was found in the fuel systems, fuel tanks, carburetors or engines of any of the fleet vehicles examined at test completion.

5.7 Engine Durability

Two matched pairs of engines from vehicles types 9 and 3 (Table 1) were disassembled at test completion for an examination of comparative engine wear results on gasohol and gasoline. The type 9 vehicles had Ford 6 cylinder, 4.92 L engines, while the type 3 vehicles had AMC 6 cylinder, 3.80 L engines. There were no apparent differences in engine wear or engine condition between similar engines that had been operated on gasohol or gasoline. Detailed photographs of the valve and cylinder assemblies are presented in Appendix 5.

5.8 Economic Considerations

From the chassis dynamometer tests, it may be concluded that from 1.5 to 1.7% savings in fuel consumption are possible by using gasohol instead

Table 10. Chassis Dynamometer Results for 88 km/h (Simulated Highway Driving)

Vehicle Type (See Table 8)	Specific Fuel Consumption (L/100km)			
	Gasoline	Gasohol	Difference (di)	di^2
A	15.11	15.72	-0.61	0.366
B	7.07	6.61	0.467	0.209
B	6.97	6.95	0.027	0.000
C	9.47	9.21	0.27	0.072
D	12.20	12.72	-0.53	0.276
E	9.39	9.01	0.38	0.144
F	14.03	14.13	-0.10	0.011
G	13.72	13.44	0.28	0.078
H	26.03	24.96	1.085	1.156
I	29.15	28.48	0.68	0.458
	143.14	141.22	1.92	2.770

$t = 1.18$

$t_{90,9} = 1.38$

$t_{85,9} = 1.10$

of gasoline. These potential savings are based on the assumption of similar unit prices for gasohol and gasoline. The probable reason for the slightly lower fuel consumption with gasohol is that gasohol tends to 'lean out' the fuel mixture, thereby increasing fuel efficiency.

There was also no apparent difference in maintenance requirements for the gasohol vehicles and the gasoline vehicles. In addition, there was no apparent evidence that the ethanol in the gasohol caused any deterioration of fuel system components.

6.0 SUMMARY AND CONCLUSIONS

The following conclusions may be drawn as a result of 22 months of fleet testing during which time the gasohol and control fleets travelled a cumulative distance of 1.75 million km:

6.1 No engine modifications or adjustments were needed to convert standard gasoline powered vehicles to gasohol use.

6.2 Based on a summary of fleet driver daily log sheets, no differences in driveability or overall vehicle performance were apparent between vehicles operated on gasohol or gasoline.

6.3 Because of gasohol availability and logistic reasons the gasohol fleet was operated in urban areas while the gasoline control fleet was operated in rural areas. Although this yielded suitable driveability comparison results, the two fleets could not be used for valid fleet fuel consumption comparisons.

6.4 Comparison of the specific fuel consumption of the 25 gasohol fleet vehicles to the specific fuel consumption of the same vehicles, operating in urban conditions, for the 12 month period prior to conversion to gasohol, permit valid fleet fuel consumption comparisons. Results of this comparison indicated no difference in specific fuel consumption for the two fleets. The specific energy consumption of similar vehicles was, however, significantly lower (90% confidence level) when operated on gasohol than when operated on gasoline. The difference in specific energy consumption varied from 2 to 107 MJ/100 km.

6.5 Chassis dynamometer tests on nine different vehicles operating alternately on gasohol and gasoline, permitted scientifically valid vehicle performance comparisons in controlled conditions. In simulated urban driving at 48 km/h the specific fuel consumption of the same vehicles was significantly lower (90% confidence level) when operated on gasohol than when operated on gasoline. Similarly, in simulated highway driving conditions at 88 km/h, the specific fuel consumption of the same vehicles was significantly lower (85% confidence level) when operated on gasohol than when operated on gasoline. Fuel consumption differences were small, varying from 1.7% in urban driving to 1.5% in highway driving.

6.6 In comparative engine dynamometer tests on a 2.3L automotive engine, the maximum power output with gasohol was about 7% greater than with gasoline. At maximum load, the brake specific fuel consumption was as much as 10% lower with gasohol than with gasoline.

6.7 There were no apparent differences in vehicle maintenance needs or engine durability between gasohol and gasoline fleet vehicles. There was no evidence of gasohol causing any deterioration of fuel system components.

6.8 Gasohol is a viable fuel alternative to gasoline. If gasohol is available at the same unit cost as gasoline, a fleet operator could probably realize from 1 to 2% savings in fleet operating costs by using gasohol instead of gasoline.

7.0 RECOMMENDATIONS

7.1 For future fleet tests it should be ensured that the test fleet and control fleet contain similar paired vehicles and operate in similar driving conditions. Due to the nature of fleet tests, however, interpretations of results obtained from actual fleet operation should concentrate on differences in driveability and maintenance. Statistical significance should not be placed on the fuel consumption data obtained from actual fleet operation, due to the wide range of uncontrolled variables.

7.2 The use of chassis and engine dynamometers should be considered essential in future fleet tests in comparing vehicles operating on different fuels. Such techniques permit valid comparisons in controlled conditions, by eliminating many of the uncontrolled variables inherent in actual field operation.

7.3 Fleet operators should consider gasohol as an attractive alternative to gasoline in future bulk fuel purchases.

APPENDIX 1

Test Procedure Used for Determining the Ethanol Content of Gasohol

Industrial Technology Centre/Manitoba Research Council

Subject: Internal Test Procedure ITC 0301, Determining the Ethanol Content of Gasohol

Instrumentation

Varian model 3720 gas chromatograph

Column	140°C	Recorder Span x 1
Injector	160°C	2mv full scale
Detector	190°C	1cm/min. chart speed
Filament	210°C	
Range	0.5mv	Integrator - Varian CDS 111, preset parameters

Column Porapak/ 80/100 mesh 6' x 1/8" OD SS
Carrier gas - helium @ 30 ml/min.

Sample Preparation

In a 125 ml separatory funnel, extract a 50.0 mL aliquot of sample with four 20 mL portions distilled water, draining the water layer each time into a 100 mL volumetric flask. Add 5.0 mL methanol to the flask and dilute to the mark with distilled water.

NOTE: The v/v% of methanol added to the sample must be the same as that added to the standard.

Standard Preparation

Prepare a working standard of ethanol in distilled water, adding 5% v/v methanol as an internal standard. A convenient standard to use is 5.0 mL ethanol (100% Liquor Control Commission) plus 5.0 ml methanol diluted to 100 mL with distilled water.

The ratio of peak areas of methanol should be around 0.91.

Chromatography

Inject 0.6 uL of the standard and of the water extracts into the column. The methanol will be eluted after 1 minute and the ethanol will elute after 2.1 minutes.

Calculation

Concentration of EtOH in sample (v/v%) =

$$\frac{\frac{\text{Area of EtOH peak in sample}}{\text{Area of MeOH peak in sample}}}{\frac{\text{Area of EtOH peak in standard}}{\text{Area of MeOH peak}}} \times \text{Concentration (v/v\%) of EtOH in Standard}$$

APPENDIX 2

Tabulated Results of Engine Dynamometer Tests on a
2.3L, Ford, Four-Cylinder Engine Using Gasohol and Gasoline

Table 11. Ratios of Brake Specific Fuel Consumption (Gasohol/Gasoline)

Engine Speed (rpm)	ENGINE TORQUE (N.m)									
	0	10	20	30	40	50	60	70	80	Maximum
1000	1.05		1.04		1.00		.97			
1500	1.08	1.01	.99	1.03	.99	1.00	.96		.91	.P[illegible]
2000	.74	1.08	.96	1.02	.97	1.01	1.02	1.00	.98	.88
2500	.99	1.04	1.01	.98	1.02	1.01	1.01	1.01	.97	1.15
3000	1.02	1.02	.99	1.01	1.02	1.01	1.01	.98	.94	.93
3500	1.02		1.02		1.05		1.02		.96	.89
4000	1.00		1.03		1.05		1.05		.95	.96
4500	1.15		1.11		1.04		1.02		.95	.96

Table 12. Comparison of Maximum Torque and Maximum Power Output

Engine Speed (rpm)	Gasoline		Gasohol	
	Engine Torque (N.m)	Power Output (kw)	Engine Torque (N.m)	Power Output (kw)
1500	122.8	14.3	138.6	21.9
2000	135.0	28.3	144.0	30.4
2500	133.7	34.8	144.3	37.6
3000	131.4	40.8	144.5	45.0
3500	131.6	47.4	140.9	50.7
4000	128.5	52.4	134.0	55.1
4500	118.4	54.3	123.4	56.7

APPENDIX 3

Statistical Analyses of Fuel and Energy Consumption Data

1. Statistical Methods

Gasohol and gasoline fleet fuel and energy consumption data were analyzed with paired difference significance tests using student's t-distribution. In performing these analyses it was assumed that the sample standard deviation was a good estimate of the population standard deviation and that the population was normally distributed. The null hypothesis (Ho) in each case was that there was no difference between the mean consumption of gasoline and the mean consumption of gasohol. Depending on the specific data, one-tailed or two-tailed tests were performed.

2. Analysis of Fleet Results

(a) Analysis of Data in Table 4, page 29 (two-tailed t test)

di	No. of Vehicle Pairs (n)	Standard Deviation (Sd)	t calculated	$t_{90,24}$
13.28	25	4.91	0.54	$\pm$ 1.71

H_0 is not rejected.

(b) Analysis of Data in Table 5, page 30 (one-tailed t test)

di	No. of Vehicle Pairs (n)	Standard Deviation (Sd)	t calculated	$t_{90,24}$
1357.7	25	159.0	1.71	$\pm$ 1.71

H_0 is rejected at the 90% confidence level.

(c) Analysis of Data in Table 6, page 32 (two-tailed t test)

di	No. of Vehicle Pairs (n)	Standard Deviation (Sd)	t calculated	$t_{90,17}$
-43.30	18	6.23	-1.47	$\pm$ 1.75

H_0 is not rejected.

(d) Analysis of Data in Table 7, page 33 (one-tailed t test)

di	No. of Vehicle Pairs (n)	Standard Deviation (Sd)	t calculated	$t_{90,17}$
-808.65	18	205.0	-0.78	1.34
H_o is not rejected.				

(e) Analysis of Data in Table 9, page 35 (one-tailed t test)

di	No. of Vehicle Pairs (n)	Standard Deviation (Sd)	t calculated	$t_{85,9}$
5.078	10	115	1.40	1.38
H_o is rejected at the 90% confidence level.				

(f) Analysis of Data in Table 10, page 37 (one-tailed t test)

di	No. of Vehicle Pairs (n)	Standard Deviation (Sd)	t calculated	$t_{85,9}$
1.92	10	0.52	1.18	1.10
H_o is rejected at the 85% confidence level				

APPENDIX 4

Results of Fuel System Compatability Tests with Gasohol

(1) Density and Mass Changes of Three Floats After 90 Days of Immersion in Esso 2000 Gasoline

Float	Mean Density (g/cm^3)		
	Before Immersion	After Immersion	Density Change
D	0.2942	0.2959	+0.0017
E	0.2973	0.2989	+0.0016
F	0.2927	0.2947	+0.0019
Average	0.2947	0.2965	+0.0017 = 0.57%

Float	Mass (g)			% Mass Change
	Before Immersion	After Immersion	Mass Change	
D	7.9217	7.9525	+0.0308	+0.39
E	7.9827	8.0008	+0.0181	+0.23
F	7.8475	7.8848	+0.0374	+0.48
Average	7.8506	7.9461		+0.37

(2) Density and Mass Change of Three Floats After 90 Days of Immersion in Gasohol

Float	Mean Density (g/cm^3)		
	Before Immersion	After Immersion	Density Change
G	0.2953	0.2962	+0.0001
H	0.2923	0.2927	+0.0018
I	0.2913	0.2924	+0.0020
Average	0.2930	0.2938	+0.0013 = 0.44%

Float	Mass (g)			% Mass Change
	Before Immersion	After Immersion	Mass Change	
G	7.9369	7.9736	+0.0367	+0.46
H	7.8103	7.8456	+0.0353	+0.45
I	7.8159	7.8460	+0.0301	+0.38
Average	7.8543	7.8884		0.43

(3) Volume Change Determination

Based on average data from above, the volume change of the floats was calculated.

- For floats immersed in gasoline

$$\text{Initial Volume} = \frac{7.8506}{.2947} = 26.63 \text{ mL}$$

$$\text{Final Volume} = \frac{7.941}{.2965} = 26.85 \text{ mL}$$

% increase in volume = 0.60%

- For floats immersed in gasohol

$$\text{Initial Volume} = \frac{7.8543}{.2938} = 26.81 \text{ mL}$$

$$\text{Final Volume} = \frac{7.8884}{.2938} = 26.85 \text{ mL}$$

% increase in volume = 0.17%

(4) Distillation Data for the Test Immersion Fuels

Esso 2000 Gasoline		
Fraction Recovered (%)	Before Test Temperature (°C)	After Test Temperature (°C)
Initial Boiling Point	31.5	32.5
5	43.0	50.0
10	49.5	58.5
20	61.5	73.5
30	81.0	86.5
40	94.0	95.5
50	102.0	102.5
60	108.0	109.0
70	117.0	118.5
80	134.0	137.0
90	170.0	172.0
95	190.0	192.5
Decomposition Temperature	197.5	198.5
Total Recovery	97.0%	97.0%

Gasohol		
Fraction Recovered(%)	Before Test Temperature (°C)	After Test Temperature (°C)
Initial Boiling Point	31.5	32.0
5	40.0	43.0
10	45.5	49.0
20	55.5	57.5
30	63.5	64.0
40	68.0	68.0
50	80.3	93.0
60	101.5	104.5
70	115.0	114.0
80	132.0	135.0
90	169.0	173.0
95	196.5	193.0
Decomposition Temperature	198.0	198.0
Total Recovery	96.0%	95.25%

APPENDIX 5

Photographs of Engine Cylinder and Valve Assemblies
After Fleet Test Completion

Reference: Section 5.7

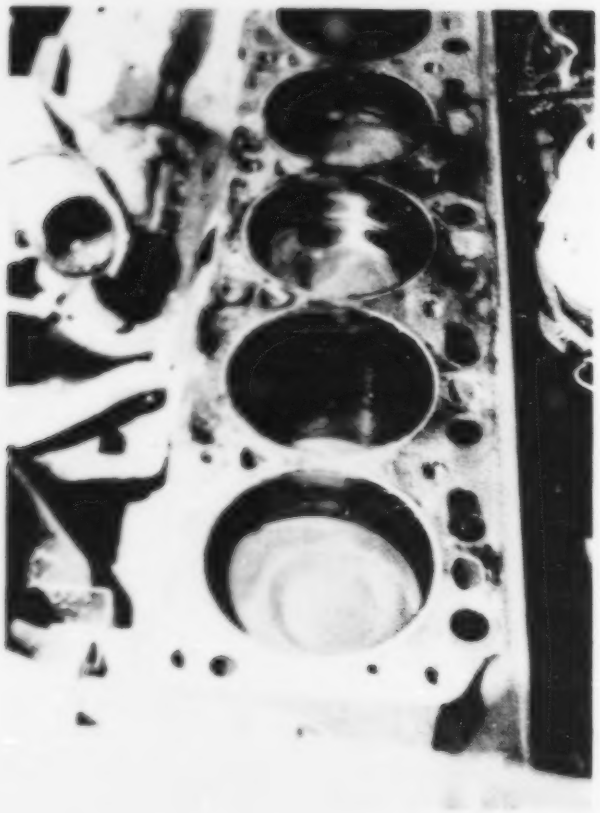

Figure 18 Type 9 Engine Cylinder Assembly (Operated on Gasohol)

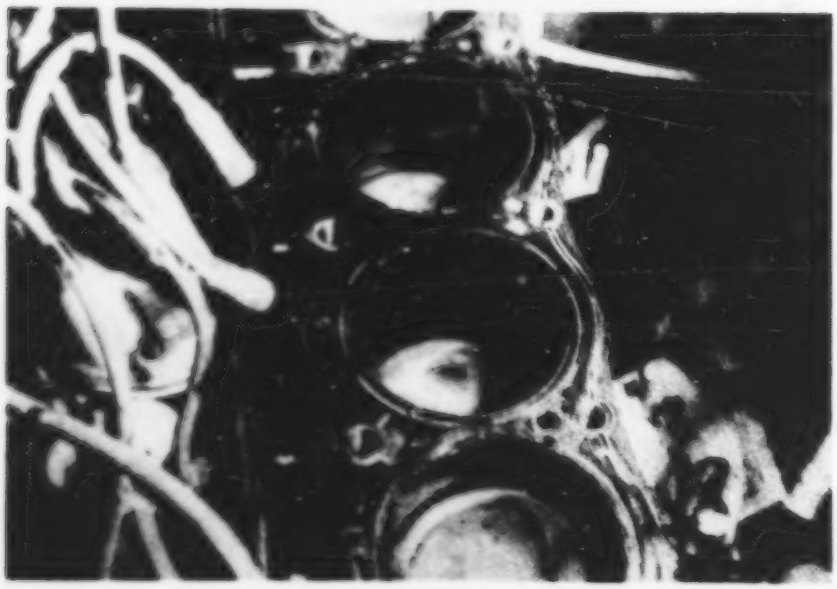

Figure 19 Type 9 Engine Cylinder Assembly (Operated on Gasoline)

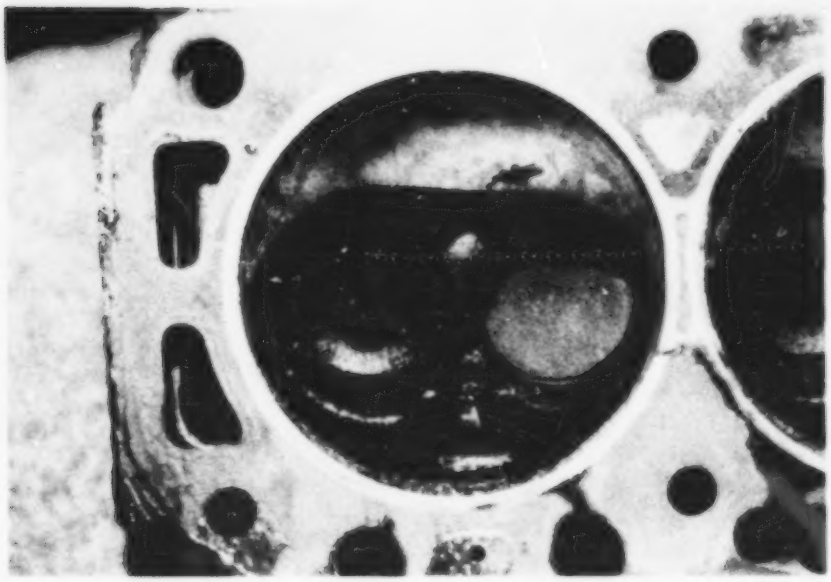

Figure 20 Type 9 Engine Valve Assembly (Operated on Gasohol)

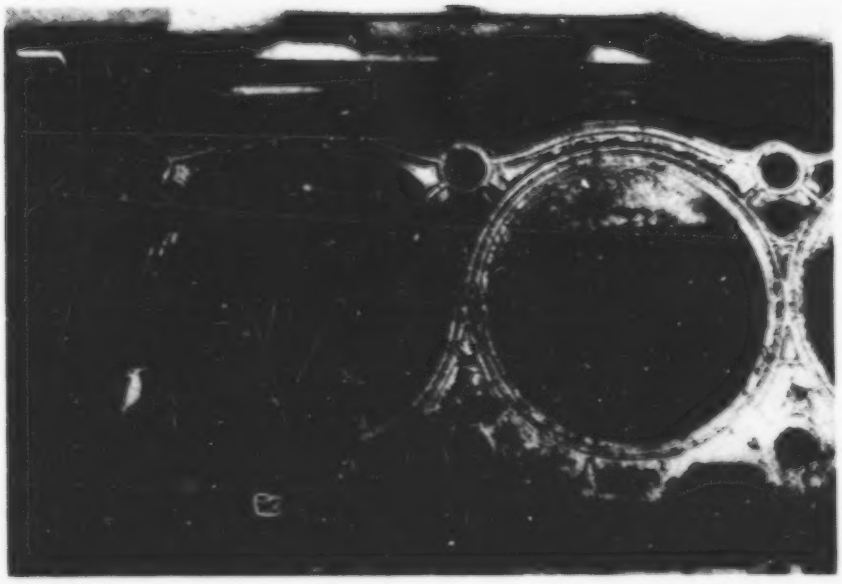

Figure 21 Type 9 Engine Valve Assembly (Operated on Gasoline)

Figure 22 Type 3 Engine Cylinder Assembly (Operated on Gasohol)

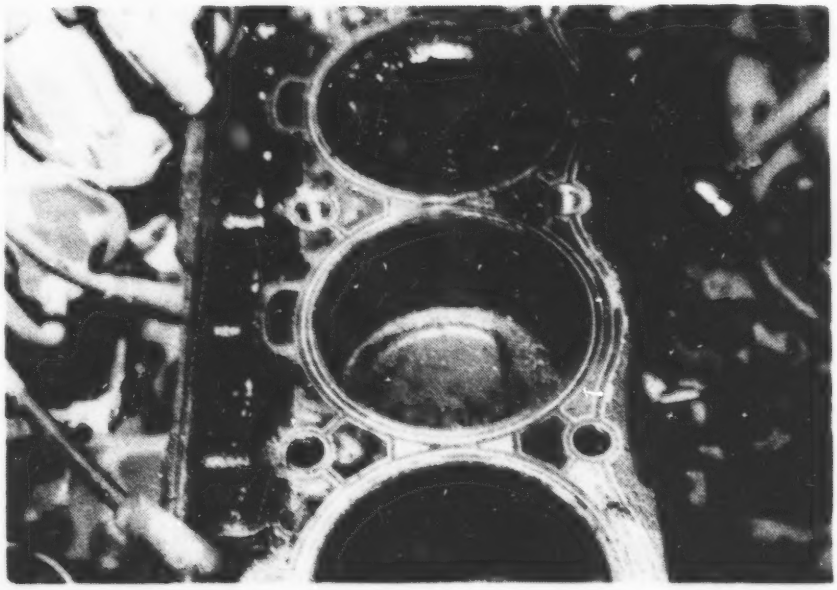

Figure 23 Type 3 Engine Cylinder Assembly (Operated on Gasoline)

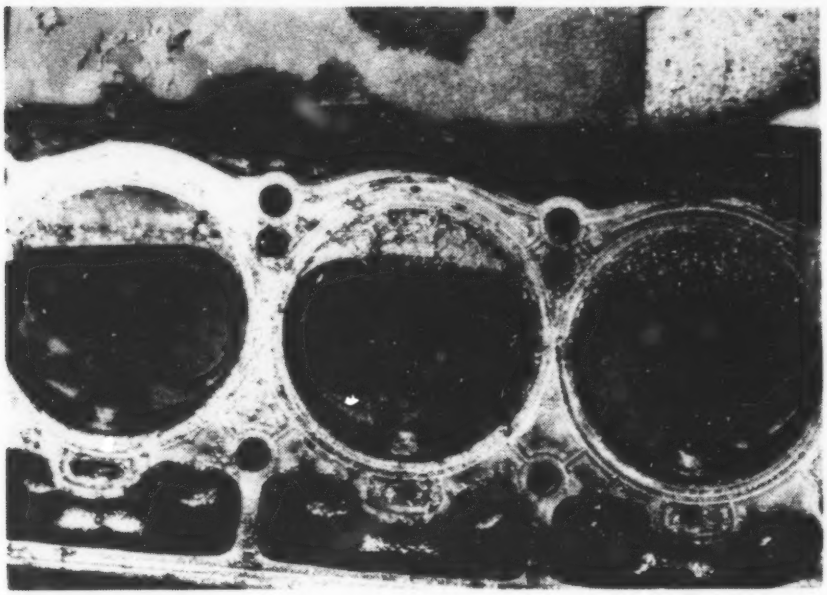

Figure 24 Type 3 Engine Valve Assembly (Operated on Gasohol)

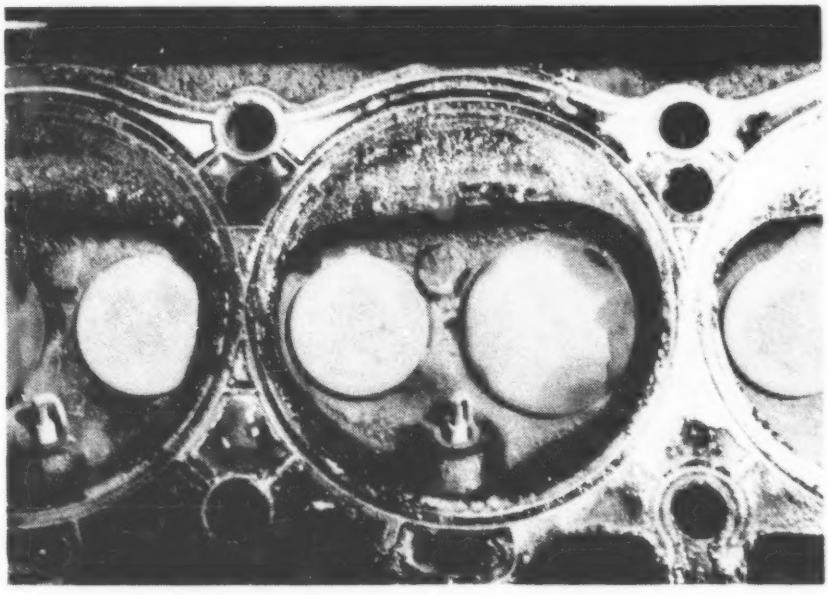

Figure 25 Type 3 Engine Valve Assembly (Operated on Gasoline)